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RESEARCH ARTICLE

Comparing Optimum Barrier Variables of Aluminium and MPET Foil Based Laminates for Coffee Packaging

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ABSTRACT

The barrier property variables for Aluminum based laminates, both under flexed and un-flexed condition, were compared with that of MPET based laminates in order to understand comparative suitability of the later for coffee packaging. Keeping the expected shelf life condition of 180 days the different barrier property variables of the sample MPET and Aluminum based laminates, at the optimality condition, were found out. At the optimum condition, Oxygen transfer rate (OTR) under flexed condition is marginally more for MPET based laminates. However, Aluminium laminates in flexed condition allowing moisture transfer (WVTR) at the rate 24.32 percent stronger than MPET based laminates which may not be good for coffee packaging.

KEY WORDS

Metalized BOPET, Barrier property, Oxygen Transfer Rate, Water Vapor Transfer Rate, Pinholes

1.0 INTRODUCTION

Metalized BOPET (Bi-axially oriented polyethylene terephthalate) or simply MPET has been in the limelight now-a-days because the end users find them economical as well as environmentally viable alternative to other forms of packaging material used for beverage , food etc. Earlier, exclusive PET (Polypropylene and polyethylene terephthalate) based laminates were proved to have poor barrier properties and hence considered not suitable for packaging of products requiring higher barrier properties like coffee [1]. In particular, therefore, the packaging materials for Coffee need to have high barrier properties which can keep oxygen and water vapor out to preserve the freshness of the product inside. Poor barrier property of the packaging material shortens the shelf life of the packaged product and hence products like Coffee cannot be packaged by PET containers known to have weak barrier property [2].

Therefore, the most widely adopted practice has been to use aluminum foil or other composite material laminated with Polyester and Polypropylene film as functional barrier materials to increase barrier property of packaging material and then use for Coffee packaging. However, the aluminum foil packaging material needs lots of energy consumption in the production process [3]. Alternatively, the improved barrier properties of MPET film have attracted many marketers and hence they have shown inclination for replacing Aluminium in packaging lamination. The great lustrous looks of the MPET in the showcase condition in the market place also attracted consumers towards this product which is in addition to the attraction resulting from better barrier properties. However, there is an absolute requirement to compare the barrier proprieties of Aluminium and MPET foil based laminates at the optimality level to develop clear understanding in terms of their superiority in providing the best level of freshness to a product like coffee in the packaged condition.

1.1 Purpose of the Paper

Understanding the barrier properties of the packaging material is very important from a technological as well as commercial point of view [4]. The most common barrier property spoilers are associated with water vapour and oxygen transfer in a packaging material [5]. These reduce the effectiveness of packaging material used for protecting and enhancing the product's commercial value. This paper, therefore, intends to find the optimum barrier property variables like water vapour, oxygen transfer etc. in a MPET based laminate and compare the same with the Aluminum based laminate. This will, in a way, allow greater understanding the optimum values of the different barriers variables under expected shelf life condition in comparative terms between MPET structure and Aluminum foil structure. Most importantly this will also allow the marketer of products like coffee, requiring high barrier properties, to judiciously select between MPET structure and Aluminum foil structure for packaging purpose.

2.0 LITERATURE REVIEW

In order to proceed with the objective of the paper, it is important to understand the components associated with increasing or decreasing of barrier properties of packaging material. Hence, we resorted to an extensive literature review on the subject understudy as discussed below.

The concept of shelf life is directly related with food packaging. It actually indicates the length of time that the packaged perishable items would get before they are considered unsuitable for sale, use, or consumption [6]. Product such as coffee is extremely oxygen sensitive, therefore, this product is required to pack with such packaging materials which have high barrier properties to maintain or enhance the product's freshness and shelf life. On the other hand, the perishable products and their shelf life depend on the surrounding environment that prevails under packaged condition [7]. Any experiment to increase the shelf life of perishable products, therefore, starts with attempt to control the environment inside the package. Controllability of moisture content, oxygen transfer rate and carbon dioxide exchange rate is of utmost importance when the producers or the marketers think of increasing the shelf life of such products by arresting naturally happening deterioration process.

Knowledge of the gas transmission properties of packaging materials is critical for a successful package design. Oxygen transmission rate (OTR) is one of the most important of the gas transmission properties [8]. OTR is the amount of O2 that can permeate through a given amount of area with pressure within a certain time frame. Any attempt to increase the shelf life of Coffee, controllability of oxygen transfer rate is of utmost importance when the producers or the marketers think of increasing the shelf life of such products. Packaging solution can provide best service to increase the shelf life of the product inside it by setting a balance between the declining oxygen content and increasing carbon dioxide level inside the package. The oxygen transfer rate (OTR) is a continuous process and can be assessed by measuring the amount of oxygen permeates at a normal rate through the package over a period of time [9]. The unit used for measuring the oxygen transfer rate (OTR) is cc/m²/24 hours. This rate of OTR, therefore, is very important to calculate for the packaging material to understand the capability and usability of the material in a particular condition. As per industry standard a packaging film is considered to high OTR resistant if the OTR rate has a range of approximately 1-10 cc/m²/24 hours. A not so high resistant packaging martial may clock an OTR rate of approximately 1,000 cc/m²/24 hours. However, a low OTR resistant packaging material can have OTR rate of even 10,000 cc/m²/24 hours.

Water vapor transmission rate or simply WVTR is another important barrier property of plastic packaging material which can affect the shelf life of the product. WVTR indicates the passage of water vapor through the packaging material. There are many food products like Coffee where water vapor control is critical. So, such water vapor sensitive foods products are required to put inside requisite high barrier packaging material to achieve desired shelf life [10]. Another important barrier related properties of packaging material are the Pinholes or simply the strains present and formed in PET films. Pinholes describe small areas that at first sight appear to have no metal coating present. It was reported that coating defects such as Pinholes routinely occur in vacuum-deposited thin films. The less number of Pinholes present in packaging material determines good barrier function and hence increased shelf life [11]. Expectedly, in the flexed condition, the number of P in holes will be more than the un-flexed one (laboratory condition). At the same time more Pinholes indicate poor barrier property of the film. So, in a nutshell, a packaging material for Coffee requires low OTR, WVTR, and Pinholes to provide higher shelf life.

3.0 METHODOLOGY

The objective of the paper is to find the optimum barrier property variables like water vapour, oxygen transfer etc in a MPET based laminate and compare the same with the Aluminum based laminate. Hence, to proceed in determining optimum barrier variables for MPET and Aluminum film laminates, 51 samples of MPET (flexed) and aluminum (flexed) laminates were collected from local markets to test their barrier property in laboratory condition. Un-flexed MPET and Aluminum laminate samples were collected from different plastic film manufacturing factories.

Out of the 51 samples collected, 10 random samples were subjected to Delamination test in laboratory through which layers were removed from another using ethyl alcohol solution. This was carried out to understand the structure of the MPET based laminates as well as Aluminum based laminates. The process started with dipping the MPET laminates in ethanol solution for about an hour. The delaminating of aluminum foil from the laminate was a much more time taking job. As there was paucity of available laboratory time so we restricted number of samples to be delaminated to ten randomly selected samples laminates only. After delamination process it was evident that the MPET based and Aluminum based laminates structure, used for food packaging, typically consisted of several functional layers as shown in table 1. MPET based structure had a 12 micron printed PET, 15 micron extruded PE, 12 micron MPET, 15 micron sealant PET and 30 micron PET and each of these layers had a functional role to play while performing as food packaging material. For example, the 12 micron printed PET allows printing to take place smoothly on it when put to use by the marketers for branding etc. The metallized layer MPET inside provided the most important barrier properties like oxygen and moisture barrier and allowed longer shelf life for the content inside. Similarly, the Aluminium based laminate replaced the MPET inside with 9 micron extruded Aluminium foil to induce barrier properties in the laminate structure.

This delamination process allowed us to understand the detailed structure of the MPET and Aluminum based film commonly used as packaging material. The MPET based film has 12µ MPET foil and Aluminium based one has 9µ Aluminium foil. After understanding the structure of the collected sample, the different barrier property variables of the laminates were measured in laboratory. For measurement of WVTR of flexible barrier films an instrument known as infrared diffusometer was

Table 1: Details of Laminate structures

Samples	Constituents of the film	Thickness in micron	Density	GSM* (g/m^2)	Resulting structure (MPET Based)
All the 10 samples	Printed-PET	12	1.4	16.8	12µPrintedPET +15µExtrudedPE+12µMPET/15 Mic Ext PE +30µPE
	Extruded-PE	15	0.92	13.8	
	MPET	**12**	1.4	16.8	
	Ext PE	15	1.4	13.8	
	PE	30	0.92	27.6	
	Total GSM			88.8	
	Constituents of the film	Thickness in micron	Density g/cm3	GSM* (g/m^2)	Resulting structure (Al Based)
All the 10 samples	PET	12	1.4	16.8	12µPET+18µPE Extruded+9µAl foil/18 mic Ext PE +45µPE
	PE	18	0.92	16.56	
	Extruded Al Foil	**9**	2.7	24.3	
	Ext PE	18	1.4	16.56	
	PE	45	0.92	41.4	
	Total GSM			115.62	

** Grammage square meter or GSM=Thickness x Density* used. Diffusometer is an instrument for making rapid measurements of the rate of water vapor transmission through thin films. The diffusometer, in laboratory condition, creates a state of 90% relative humidity at 100°F on one side of a film. The infrared detector fitted on the WVTR machine thereafter measures the rate of moisture build up. This rate is actually the WVTR rate. This test data served the purpose of understanding the important property i.e. moisture barrier of the sample laminates collected. A standard Oxygen Permeability Tester (OPT) machine was used to test the ability of the sample laminates to allow oxygen to permeate through it in a specific time i.e. the OTR rate. All the result data in respect of OTR and WVTR were recorded with great caution. We calculated shelf life of the samples films with the help of Accelerated Age Testing Method known as Arrhenius Reaction Rate Theory. One key property of flexible barrier material is the resistance against repetitive strain, which is called, flex durability, or Gelboflex. Through the use of Gelbo tester or Flex Resistance Tester machine (FRT) repeated strains were created on the films and numbers of strain or the Pinholes were determined by use of colored turpentine by allowing it to stain through the pin holes onto white backing.

3.1 Optimum barrier combination: Aluminium vs. MPET (un-flexed)

In order to understand the barrier property of MPET laminate and aluminum based laminate , 51 samples of MPET (flexed) and aluminum (flexed) were tested in the laboratory as stated in the methodology section and following resultant data (table 2) in respect of OTR, WVTR and Pinholes were found out. Similarly, tests were also conducted on 51 samples of MPET (un-flexed) and aluminum (un-flexed) and their resultant test data can be seen in the following table 3. Also Arrhenius equation was utilized to understand the Shelf life of the sample laminates associated which can also be seen in the table 2 and 3 as well.

Table 2: Descriptive Statistics Aluminium foil un-flexed

Variables (N=51)	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Shelf Life	38.00	150.00	188.00	177.68	6.725	45.22
OTR	.0864	.0123	.0987	.051993	.02597	0.001
Pinhole	223.00	123.00	346.00	228.23	47.46	2252.86
WVTR	.0110	.0015	.0125	.006917	.0023639	.000

Table 3: Descriptive Statistics: MPET un-flexed

Variables (N=51)	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Shelf Life	60.00	120.00	180.00	154.00	15.4142	237.6
OTR	.2332	.1234	.3566	.22118	.05617	.003
Pinhole	.46	.02	.48	.2578	.11577	.013
WVTR	.3444	.1123	.4567	.22299	64190	.004

3.2 Optimum barrier properties for Aluminium and MPET (un-flexed)

In order to understand the relationship between the barrier variables and shelf life, involved in 51 sample test result, we used exponential dependency relationship since it was evident that the data were randomly recurring in an independent event sequence. So exponential equation,

$$Y= e^{ax+by+cz}+ \text{Constant}$$

was considered. Here, the shelf life is taken as dependent variable and OTR, WVTR and Pinhole are independent variables. The laboratory captured data of barrier property variables were subjected to standard statistical optimisation techniques. First step was fitting the exponential curve in the following way.

Let the equation be $Y= e^{ax+by+cz}+$ Constant
Ln Y= ax+by+cz + Constant (in log form)
In practical form it becomes (in case of Aluminium laminates)
Ln Y (Shelf life Aluminium) = A (OTR aluminium) X+ B(WVTR aluminium)Y+ C(pinhole aluminium) Z+ Constant
Then, through linear regression analysis using SPSS statistical package the coefficients were found out in case of Aluminium laminate data.

Ln Y = 5.712 (CONSTANT) - 0.272(OTR) - 1.425 (WVTR)-$\left(\frac{1}{4.884}\right)5\ PINHOLE$

Now, we considered the above equation as maximising Linear Programming Problem (LPP) i.e. at what variable value of OTR, WVTR and Pinhole the shelf life would be 180. This is in equation form became as follows
Ln Shelf Life= 5.172- 0.272(OTR)- 1.425(WVTR) - $\left(\frac{1}{4.884}\right)5 Pinhole$ = 180
So, in LPP format the problem took the shape in the following way

By changing OTR, WVTR &Pinhole
Subject to:
0.09865 ≥ OTR ≥ 0.0123
346 ≥ Pinhole ≥ 123
0.0125 ≥ WVTR ≥ 0.00147

The above maximum & minimum values of variables were taken from the corresponding maximum and minimum values from the sample statistics. Now this was solved as an optimisation problem using the maximum and minimum condition stipulated above. In a simple way, the LPP was an optimising problem and was solved using MS excel solver under the condition of shelf life as 180. The optimum values so obtained, after solving the LPP in respect of OTR, WVTR, and Pinholes can be seen in the table 4 below. Proceeding in the same direction as above we calculated the parameters like OTR, WVTR, and Pinholes in case of data related to MPET samples and respective optimal values can be seen in the table 4 also.

Table 4: Optimal barrier properties of Aluminium and MPET (un-flexed) under 180 day shelf life

Parameters (N=51)	Aluminium (un-flexed)	MPET (un-flexed)
OTR	0.06571	0.2283
WVTR	0.00873	0.21408
Pinhole	199	0.02

3.3 Optimum barrier combination: Aluminium vs. MPET (flexed)

In order to understand applicability of MPET material as an alternative to aluminum coffee packaging, 51 samples of MPET (flexed) and aluminum (flexed) were tested in the laboratory and following resultant data in respect of OTR, WVTR and Pinholes can be seen below (table 5 and 6) along with Shelf life data.

3.4 Optimum parameters for MPET (flexed)

Proceeding in the same direction as stated above, we found the following (table 7) expected optimal barrier property parameters in respect of Aluminium and MPET (flexed) laminates under 180 day shelf life condition.

4.0 CONCLUSION

The main objective of the paper was to highlight the optimum barrier property variables in a MPET based laminate and compare the same with the Aluminum based laminate. This will, in a way, allow understanding the optimum values of the different barriers variables under the mostly expected shelf life condition of packaging laminates like MPET and Aluminum foil. In addition, the comparison between these two also through light whether MPET based structure can replace the Aluminum foil based structure in packaging Coffee. The entire result of the laboratory process executed on two types of samples has been put in the table 8. It can be seen from the table that the most common Aluminum based structure used in the market

Table 5: Descriptive Statistics Aluminium Flexed

Variables (N=51)	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
OTR	.2111	.1654	.3765	.240040	.054845	.003
WVTR	.3424	.1342	.4766	.249152	.053819	.003
PINHOLE	.58	.07	.65	.2763	.10535	.011
Shelf Life	60.00	120.00	180.00	153.1346	15.9325	253.84

Table 6: Descriptive Statistics MPET Flexed

	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
OTR	.1231	.2090	.3321	.238528	.0262580	.001
WVTR	.2987	.1223	.4210	.228460	.0573311	.003
PINHOLE	38.00	150.00	188.00	177.7308	6.66603	44.436
Shelf Life	223.00	166.00	389.00	308.5962	55.45472	3075.226

Table 7: Optimal barrier properties of Aluminium and MPET (flexed) under 180 day Shelf life

Parameters	MPET flexed	Aluminium flexed
OTR	0.24598	0.21993
WVTR	0.23408	0.2910
Pinhole	0.02	200

place consisted of 12µPET+18µPE Extruded+9µAl foil/18µExt PE +45µPE where 9 micron thickness Aluminium foil exist. Similarly, the most common comparable MPET film structure with Aluminum based structure consisted of 12µPrintedPET+15 µExtrudedPE+12µMPET/15 Mic Ext PE +30µPE wherein 12 micron thickness of MPET film exist. The optimum barrier property comparison between the MPET and Aluminium, at this stage, is of utmost importance as product like coffee characteristically requires being of high barrier property to check loss of aroma, flavour etc with the passage of time. A close look in to the optimum combination of three important barrier properties, connected with aluminum and MPET based thin film flexible packaging like OTR, WVTR and Pinholes when shelf life remained constant i.e. 180 days, indicates that under flexed condition OTR is marginally more for MPET and only by 10.59 percent. However, in case of moisture transfer (WVTR) rate, Aluminium in flexed condition is showing 24.32 percent stronger which may not be good for coffee packaging.

This is an important finding in the sense that even after passage of certain time MPET film will be able to retain coffee aroma and taste. In addition, number of Pinholes in MPET, both in flexed and un-flexed condition, are much less in number than Aluminum foil. However, in un-flexed condition, both OTR and WVTR in Aluminium based foils are showing much better barrier properties than MPET. These, indicate that though Aluminium based laminates under un-flexed condition showing better barrier properties but MPET under flexed condition are greatly comparable with Aluminum based laminates.

Table 8: Optimal barrier properties of Aluminium and MPET (flexed) under 180 day shelf life

Sl No	**Parameters**	**MPET structure**	**Al foil structure**	**Remark**
1	Film structure	12µMPET	9µAl foil	Randomly selected samples when underwent Delamination test revealed this to most common structure
4	For Optimum structure OTR (Flexed)	0.24598 cc/m^2/day	0.21993 cc/m^2/day	OTR is marginally more for MPET (by 10.59 percent)
5	For Optimum structure WVTR (Flexed)	0.23408 g/m^2/day	0.2910 g/m^2/day	WVTR is considerably more for Aluminium (by 24.32 percent)
6	For Optimum structure Pinholes(Flexed)	0.02	200	Pin holes are much less in MPET hence better for coffee packaging
7	For Optimum structure OTR (un Flexed)	0.22830 cc/m2/day	0.06571 cc/m^2/d	OTR is better for Al (about 71.22 percent)
8	For Optimum structure WVTR (un Flexed)	0.21402 g/m^2/day	0.00873 g/m^2/day	WVTR is better for Al (about 95.92 percent)
9	For Optimum structure Pinholes(un Flexed)	0.02	199	Pinholes are less in MPET

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